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HUGHES TOOL COMPANY · AIRCRAFT DIVISION
Culver City, California

Report 285-11 (62-11)

CONTRACT NO. AF 33(600)-30271

HOT CYCLE ROTOR SYSTEM THERMAL ANALYSIS, PART II

March 1962

HUGHES TOOL COMPANY -- AIRCRAFT DIVISION
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for

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FOREWORD

This report has been prepared by Hughes Tool Company - Aircraft Division under USAF Contract AF 33(600)-30271 "Hot Cycle Pressure Jet Rotor System", D/A Project Number 9-38-01-000, Subtask 616.

The Hot Cycle Pressure Jet Rotor System is based on a principle wherein the exhaust gases from high pressure ratio turbojet engine(s) located in the fuselage are ducted through the rotor hub and blades and are exhausted through a nozzle at the blade tips. Forces thus produced drive the helicopter rotor.

This is a supplement to HTC-AD Report 285-10 which covers the thermal analysis of the constant section of the rotor blade as design progressed. Here, coverage is given for the hub section. This report is in partial fulfillment of Item 4e, which pertains to Design Analysis performed under Item 4b of the contract.

SECTION 1

SUMMARY

Provided herein is a survey of estimated temperatures in the blade root and hub section of the initial hot cycle rotor. Initial thermal analysis indicated a necessity of applying insulation to prevent high temperatures in this area. Aluminum clad shields were subsequently installed over the hot gas ducting. Due to the conservative approach used in the calculations, the highest predicted component temperatures remain much below acceptable limits. No thermal problems are anticipated in this area of the rotor.

SECTION 2

INTRODUCTION

In the early phase of development of the Hot Cycle Rotor System, considerable work was done in computing air flows, heat losses, and component temperature distributions. The results of that effort were later made obsolete by the upgrading of some of the design requirements. The final thermal analysis of the blade root and hub section constitutes repetition of the previously reported work, modified to conform with the newest criteria. Therefore, no attempt is made to include herein any facets of the study which were already discussed before.

At the end of 1959, practically all thermal analyses, including the predicted component temperatures, were completed. A formal report (Reference 1) presented the results of thermal studies utilizing the IBM calculating programs. However, those programs and the scope of the report were limited to a discussion of the constant section of the blade. The estimates regarding temperature distribution in the blade root and hub section were withheld until a satisfactory insulation was found and approved for the design. The purpose of this report is to present that information and thus provide a supplement to Reference 1.

The center section of the rotor reviewed in this report is shown in Figure 1. The assembly is cooled with the centrifugally pumped air flowing between the hot duct and the load carrying components. The cooling air enters into the hub near the center and is discharged through the ports in the blade skin at approximately a six foot radius. Alluminum clad shields installed around the hot duct provide an effective control of radiation.

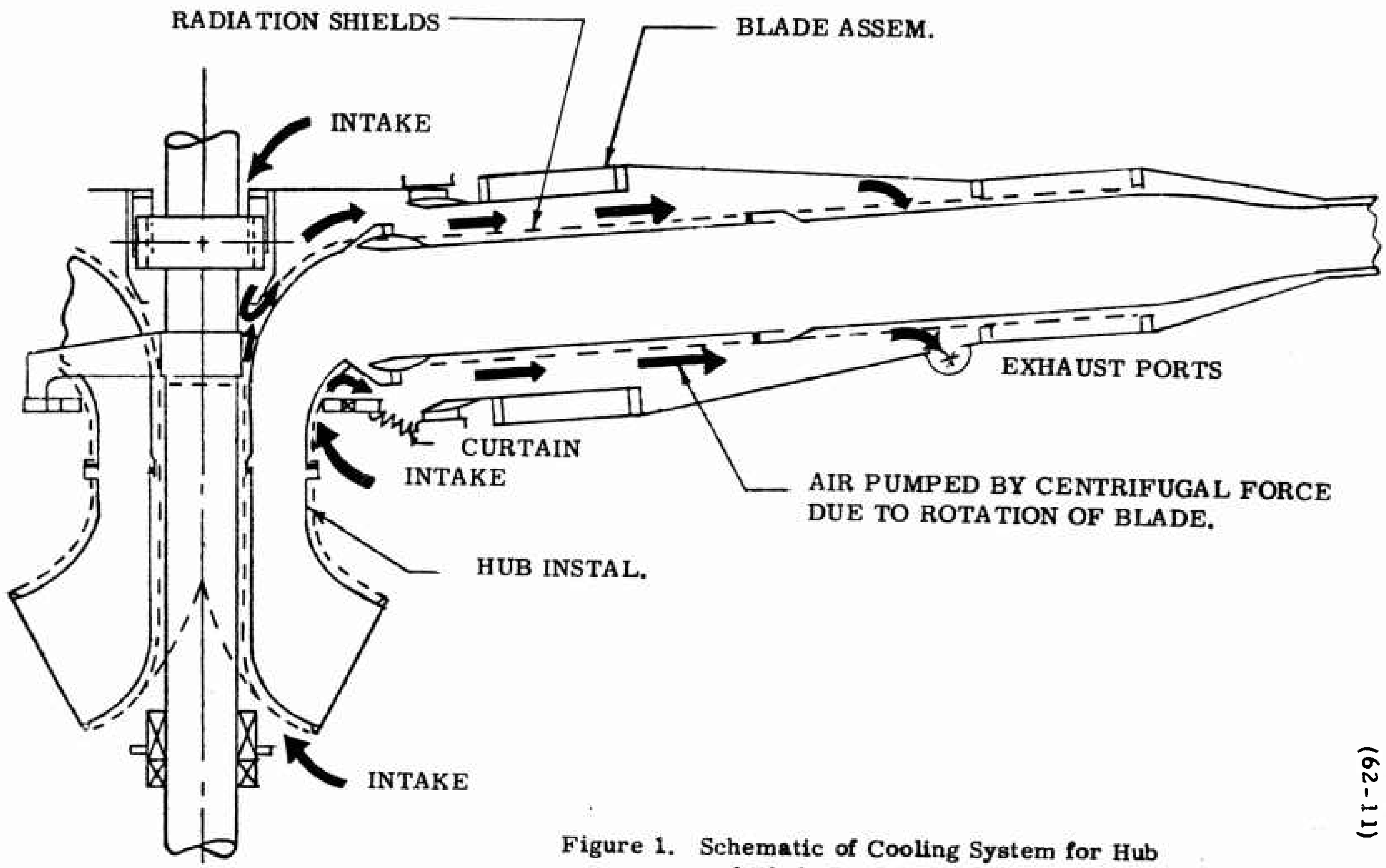

Figure 1. Schematic of Cooling System for Hub and Blade Root Components.

SECTION 3

DESIGN CRITERIA

This analysis, similarly to the Thermal Analysis, Part 1, (Reference 1) was based on the following data:

(1)	Gas temperature	1200°F
(2)	Ambient Air Temperature	100°F
(3)	Altitude	Sea Level
(4)	Gas Flow	15.5 lb/sec/blade
(5)	Duct Area	54.8 sq. in/blade
(6)	Blade Tip Speed	700 ft/sec.

The above criteria represent generally the most severe conditions of maximum temperature levels expected with a growth version of the General Electric T64 engine.

SECTION 4

ACCURACY OF RESULTS

The analysis employed herein to determine temperature distributions in various components used a conventional application of steady state heat transfer theory, as was done in References 2 and 3. The estimates are somewhate approximate because of the intricate distribution of heat flows in complex, built-up structures and the assumptions inherent in the calculation of heat transfer coefficients. A conservative approach and pessimistic assumptions were used to prevent any possiblity of too optimistic conclusions. The principal source of deviations from the estimated values are expected to be inaccuracies in computing the centrifugally pumped cooling air flow. Error should be about 100°F or less for the higher temperature components. To estimate component temperatures for gas temperatures other than 1200°F, the following interpolation equation may be used:

$$T = 100 + (T_{1200} - 100) \frac{T_{gas} - 100}{1100}$$

Implicit in its use is the assumption that the heat transfer coefficients and material properties do not change with temperature. The greater the deviation of gas temperature from 1200°F, the less accurate this assumption becomes.

SECTION 5

CONTROL OF HEAT FLOW

Throughout the blade root and hub assembly the centrifugally pumped air provides an effective barrier to convective heat transfer. For the purpose of analysis, the transmission of heat by convection is considered to be negligible or of secondary importance. All calculated component temperatures are based on the assumption that heat is transferred from the hot duct to the hub assembly by radiation alone. It was further assumed that the radiating surfaces would be coated with silver having an emissivity of 0.04. That is to say, if an insulating material is provided other than the silver coating, it must have the ability to reduce the heat transfer rate to that of the two radiating silver surfaces. This was accomplished by providing aluminum clad radiation shields around the hot gas duct.

Although, in principle, it is simple to control the structure's temperature by insulation, in practice, many considerations severely limit the acceptable materials. Extensive research has been conducted before radiation shields were approved and installed in the hub as shown in Reference 4. After considering the alternatives of silverplating and insulation, it was decided that the use of thin metal shields with aluminum surfaces offered the most practical method of heat control. The use of radiation shields not only greatly reduces the amount of radiant heat flux, but the heat flux due to convection is also reduced by a factor of two. The combination of these two effects makes the radiation shield a more efficient heat barrier than silverplating under all conditions.

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SECTION 6

RESULTS

Estimated temperatures for the rotor hub and the blade root components. (See Figure 2 for the component and temperature locations.)

All estimates listed below were made with an assumed duct wall temperature of 1200°F and an ambient temperature of 100°F. Allowances were made for increased emissivity caused by dirt and oxidation on the polished surfaces. The temperature distributation in the complex components such as the aluminum ribs with reinforcing steel plates was determined on the assumption of independent heat transfer through the various segments of the part. Conventional methods were used throughout in the analysis.

Location No.	Name of Component	Local Conditions	Temp. (°F)
1	Mast at thrust bearing lower region	Steel Mast, Cad Plate. An Aliron shield with 1/4 in. air gap is required over the upper surface of the bearing. No shield should be used on the lower surface which would interfere with the natural convection cooling.	150°
2	Mast just above thrust bearing	Steel Mast, Cad Plated	370° without shield. 160° if 1/4 air gap Aliron shield applied to mast.
3	Mast 16.00 in. below tilt axis	Steel Mast, Cad Plated Aliron shields with 1/4 air gap are required on the duct above and below the seal. A shield should be also included between the seal and the mast to deflect leakage air away from the mast.	Av. 360° Max. 500° under the titanium spacers

Location No.	Name of Component	Local Conditions	Temp. (°F)
13	Blade Strap at Inboard Fitting	Cor. Res. Stl, Bare	250°
14	Blade Strap at Sta. 40	Cor. Res. Stl, Bare	160°
15	Blade Strap at Outboard Shoe Tangent Point	Cor. Res. Stl, Bare	260°
16	Floating Hub Inboard of Flapping-Feathering Bearing	Steel, Cad Plated	120°
17	Articulate Duct Gimbal Ring	Steel, Nickel Plated Cooling air circulated inside a radiation shield	200° without leakage 270° with 1% leakage
18	Articulated Duct Gimbal Bearing	Cor. Res. Steel Bracket, bare	350°
19	Flapping-Feathering Bearing Ball	Alum. Alloy Ball	400°
20	Blade Inner Surface, Sta. 28	Alum. Alloy, Alclad	215°
21	Blade Skin, Sta. 33 to 63	Alum. Alloy, Alclad	280°
22	Blade Skin at Sta. 28	Alum. Alloy, Alclad	140°
23	Blade Skin at Sta. 73	Alum. Alloy, Alclad	215°

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Location No.	Name of Component	Local Conditions	Temp. (^oF)
24	Blade Inner Web between ribs at Sta. 63 & 73 (temp at Sta. 73)	Alum. Alloy Web, Alclad	335° (290° for gas temp = 1040°)
25	Outboard Articulated Duct Seal Fitting, Sta. 42, (Dwg. 285-0182)	Cres, Type 347, bare	800°
26	Duct Wall, Sta. 42	Cres, Type 347, bare	1170°
27	Inboard Articulated Duct Seal Housing, Sta. 15.5	Cres, Type 17-4PH, bare. Aliron shield with cooling air circulated inside	550° without leakage 950° with 1% leakage

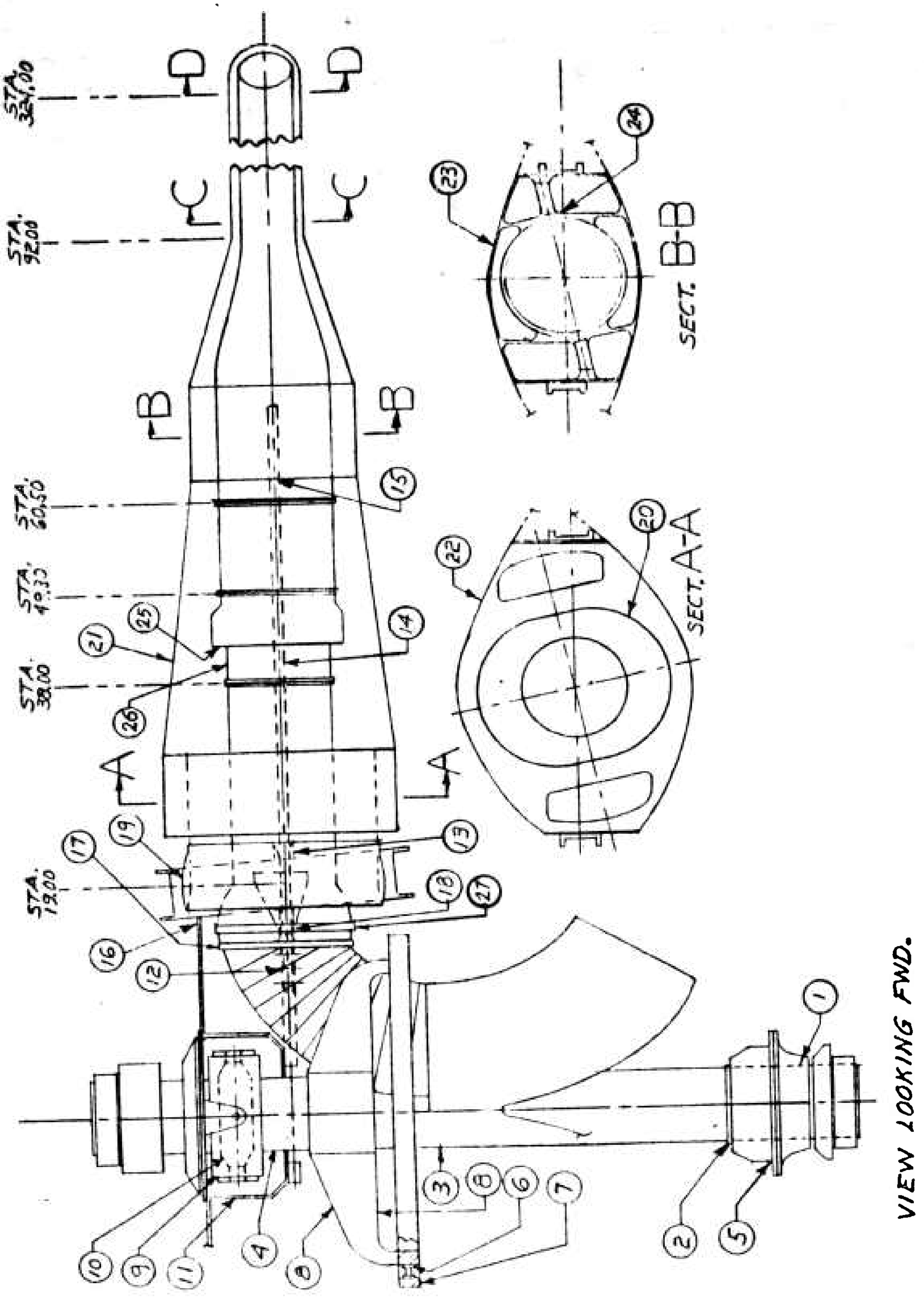

Figure 2. Temperature Location Chart

SECTION 7

CONCLUSION

Results from the thermal analysis presented and discussed in the preceding paragraphs do not indicate any temperature problems in the blade root and hub section of the Hot Cycle Rotor System. It is important to note, however, that in order to reduce the radiation heat transfer, low emissivity radiation shields were required. The shields were made of steel 0.004 in. thick having aluminum clad on both sides of .0005 in. thickness. Actually a 1/4 in. gap between the hot surface and shielding provided an excellent heat barrier for convective transmission. The design and installation of the rigidized and preformed shields did not present any problems. It is to be expected that the over-all effectiveness of this type of insulation in many respects exceeds that of silver plating.

It is estimated that the hottest spots in the working parts of the hub assembly and in the root of the blade will be sufficiently cool to eliminate excessive temperature differentials between various parts. Also, the over-all configuration of the hot gas ducts, insulation shields and cooling air passages is designed to minimize any effects of hot gas leakage.

SECTION 8

REFERENCES

1. Warner, E. E., and Kytola, J. W., "Thermal Analysis" Item 4, HTC-AD Report 285-10, June 1960.

2. LaForge, S., Shyffer, B., Rittamel, F., "Systems Study" Item 2, HTC-AD Report 285-4, February 1956.

3. Boswell, C. C., "Rotor System Preliminary Design" Item 3, HTC-AD Report 285-7, September 1956.

4. HTC-AD Dwg. No. 285-0590, Insulation - Hub Ducts.

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